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DISPOSAL OF RADIOISOTOPES - A METHOD OF
EVALUATING POTENTIAL HAZARD

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DISPOSAL OF RADIOISOTOPES - A METHOD OF EVALUATING POTENTIAL HAZARD

Conrad P. Straub*

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Abstract

Brief mention is made of techniques now in use for determining radioisotope hazard. A study was made of data available from the Operations Division, Oak Ridge National Laboratory on radioisotope shipments. These data, which included numbers of shipments and numbers of curies shipped in each month during the period August 1946 or July 1947 through December 1950, are illustrated graphically. Since the number of curies of each radioisotope shipped are known and the maximum permissible concentration for that radioisotope has been suggested, the volume of water required for dilution to the tolerance concentration could be determined. These computations, which were based on several stated assumptions and included the effects of decay, show that there is immediate need for setting standards and procedures for the safe handling and disposal of strontium and perhaps other long-lived radioisotopes.

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Prior to World War II the use of radioisotopes was limited essentially to cyclotron-produced radioactive materials. However, with the addition of radioactive materials produced in the pile, either fission products or irradiated elements, there has been a great expansion in the use of radioisotopes in research, medicine and industry. Increased uses of radioisotopes have made necessary a study of the disposal of such materials and the need for determining upper limits of permissible discharges.

Recognizing its responsibilities the Atomic Energy Commission (AEC), through the Isotopes Division, has prepared and released interim recommendations for the disposal of radioactive wastes by all types of Commission users (1). These recommendations were confined primarily to methods of disposal for iodine-131, phosphorus-32 and carbon-14, because together they accounted for 90 per cent of the activity of the radioisotopes shipped at that time (1948). In the Interim Recommendations consideration is given to the volume of sewage flow from the particular institution in order to evaluate the liquid dilution available, to the addition of a stable compound of the particular element discharged, to the maximum activity that may be discharged in an interval of time, and to the need of regular radiation surveys of the plumbing system.

In the discussion to follow radioisotope hazard classifications will be mentioned briefly, reference will be made to recent maximum permissible concentration (MPC) values reported to be under consideration by the Subcommittee on Internal Dose of the National Committee on Radiation Protection,

a method will be presented for estimating the degree of hazard resulting from the shipment of radioisotopes from Oak Ridge National Laboratory (ORNL), and finally, some conclusions will be indicated based upon the results presented.

HAZARD CLASSIFICATIONS

Radioisotope hazards may be evaluated by several means; according to 1) use, 2) half-life, 3) energy and character of radiations, 4) degree of selective localization in the body, and 5) rates of elimination. The last four factors are considered in the determination of the MPC values. As stated earlier the Interim Recommendations (1) were confined primarily to I^{131} , P^{32} , and C^{14} since these accounted for 90 per cent of the radioisotopes shipped. This was true at the time the recommendations were prepared (late 1948), but is no longer true as indicated by the data in Table I, since for the period August 1946 through December 1950 the I^{131} , P^{32} and

Insert Table I

C^{14} represented about 60 per cent of the total millicuries shipped. However, when the millicuries of Co^{60} (metal), which probably never would be discharged into the sewerage system, are subtracted from the total millicuries of radioisotopes shipped the percentage of I^{131} , P^{32} and C^{14} shipped again approach the 90 per cent figure. This change in ratio is of importance and a study should be made of recent shipments to determine for what radio-

isotopes standards and procedures for safe handling and disposal should be developed to reduce the possibility of contaminating sewerage systems and water courses.

A more complete classification of hazard, in terms of body absorption, is given in Table II which was taken from Handbook 42 (2).

Insert Table II

Included in the very dangerous category are such radioisotopes as Ca^{45} , Fe^{55} , Sr^{90} , Y^{91} , Zr^{95} , Ce^{144} , Pm^{147} , and Bi^{210} .

The MPC values tentatively reported by Morgan*(3) are another

* Under consideration for release by the Subcommittee on Internal Dose of the National Committee on Radiation Protection in Chicago, Illinois, January 16, 1951. Subcommittee membership includes: K.Z. Morgan, Chairman, A.M. Brues, G. Failla, J.C. Hamilton, H. Lisco, L.D. Marinelli, H.M. Parker, C.H. Perry, J.E. Rose, L.S. Taylor, and Shields Warren.

expression of hazard. These will be found in Table III and are given on the

Insert Table III

basis of continuous exposure (considered to be 10^4 days for purposes of calculation when dealing with radioisotopes like Ra^{226} , Pu^{239} or Sr^{90} that have a long effective half-life) in terms of microcuries of radioisotope per cubic centimeter of water or air. The values are believed safe for indefinite use of all radioisotopes listed (4), with the possible exception of a few such

as Ra^{226} , Pu^{239} (both alpha emitters) and Sr^{90} (beta emitter). Until more is known about these radioisotopes the values noted probably should be reduced by a factor of 10 to be on the safe side.

DISPOSAL OF RADIOISOTOPES

Two general methods are noted in the Interim Recommendations (1) for the disposal of radioactive wastes. These are:

- A. Dilution and dispersion. This includes dilution with stable isotopes of the same element in the same chemical form and/or dilution with other media such as water or air.
- B. Confinement and control. This includes dilution and confinement; dilution of the radioisotope with water if necessary to make concrete and storage of the concrete blocks for radioactive decay; and concentration and confinement, as for example, evaporation of the waste material and storage of the resultant slurry in either tanks or by burial in suitable receptacles.

These methods are utilized in the Interim Recommendations prepared for the disposal of I^{131} , P^{32} , and C^{14} by off-Commission users. Further reference to the disposal of radioactive wastes from laboratories and clinics may be found in a recent bulletin released by the AEC (5) and in material reported by the writer (6)*. In addition to these references to the radio-

*An expansion of this material is to be prepared for publication in a future issue of NUCLEONICS.

active waste disposal problem, the Subcommittee on Waste Disposal and Decontamination of the National Committee on Radiation Protection soon will release its findings and recommendations on this subject.

ISOTOPE SHIPMENTS

Before any attempt can be made to estimate the possible hazard associated with the use of radioisotopes by off-Commission users, information on the number of shipments and on the number of curies of radioisotopes shipped must be obtained. Such information is available from the Operations Division, ORNL, for the period August 1946, when the first shipments were made, through December 1950. Figure 1 shows the number of

Insert Figure 1

shipments that have been made monthly to off-Commission (non-Project, non-AEC), Commission (Project, AEC) and foreign users since the start of the program. During the past year the total number of shipments have averaged about 650 per month with a maximum of 791 in May. As of December 31, 1950 a total of 19,427 shipments had been made of which approximately 78 per cent or 17,150 were off-Commission, 17 per cent were Commission, and the remaining 5 per cent were foreign shipments. On the basis of total curies shipped the values were 75, 23, and 2 per cent, respectively. To show the number of curies shipped (July 1947 through December 1950) Figure 2* was prepared.

*The data in this and subsequent figures are given for the period July 1947 through December 1950 instead of from August, 1946, as shown in Figure 1. Because of this omission the curves show data covering 96.2 per cent of the total curies shipped (other than Co⁶⁰ metal) rather than 100 per cent. Co⁶⁰ metal accounted for 36.3 per cent of the total curies shipped.

Insert Figure 2

Maximum shipments occurred in June and December 1950 and were in excess of 160 curies; during the remainder of the year the total monthly shipments varied from approximately 30 to 80 curies. The number of curies of $\text{Sr}^{89} + \text{Sr}^{90}$ and Y^{90} , I^{131} and P^{32} , and of all other radioisotopes shipped are indicated in Figure 2.

Figures 1 and 2 show that during 1950 there had been a rapid increase in the number of shipments and in the number of curies shipped, that more strontium had been shipped, and that many curies of other radioisotopes had been shipped. In fact, during some months, the number of curies of all other radioisotopes shipped exceeded the total number of curies of strontium, iodine and phosphorus shipped.

ESTIMATION OF HAZARD - DILUTION METHOD

Since the number of shipments and the number of curies of radioisotopes shipped during a particular month have little direct significance from a public health standpoint, an attempt was made to evaluate the possible increase in the degree of hazard associated with increased shipments of radioisotopes to off-Commission users. Our primary concern is with off-Commission use of radioisotopes since these may be discharged into sewerage systems or water courses after use.

Before an estimate of the potential hazard can be made at the point of shipment (ORNL), it is necessary to have some indication of the MPC of each radioisotope in water and the number of curies of radioisotopes shipped during

the period. The most recent MPC values have been given in Table III. Since not all radioisotopes listed in Table III are shipped by the Operations Division, ORNL, Table IV, which shows some of the radioisotopes shipped, was

Insert Table IV

prepared.*

*The half-life of the radioisotope is also shown and was taken from reference (7).

If the number of millicuries of each radioisotope shipped in a given increment of time is divided by the tentative MPC for that radioisotope in water, a value in terms of volume is obtained.** This volume is equiva-

**
Millicuries shipped/MPC in millicuries per cc = cc

lent to the dilution required to render the given amount of radioisotope innocuous (innocuous in the sense that no apparent injury will result from continuous exposure to the radioisotope based on our present knowledge (see statement under Hazard Classifications)).

In the initial computations the following assumptions were made in estimating the quantity of water required for dilution:

1. The activity is assumed constant - no decay. Actually the radioactive decay of the radioisotope is not negligible and is considered in the next section of this report.

2. The radioisotope is discharged completely - no loss through usage, and
3. Each radioisotope acts independently.

No Decay

When these assumptions are considered in the computation of the dilution water requirements for the radioisotopes shipped in each month since July 1947 certain trends, shown in Figure 3, are obtained. The volume

Insert Figure 3

of dilution water required for each isotope shipped was computed, the amounts were totaled and plotted. The shaded areas indicate the volume of dilution water required to reduce to the MPC value the strontium and iodine shipped, and the unshaded areas represent the amount of dilution water required for the remaining radioisotopes listed in Table IV. Except for a few months during the period 1947 through 1949, the amount of dilution water required was determined by the I^{131} shipped; however, during the remainder of the period, with the exception of November and December 1950, the situation was quite different inasmuch as the volume of dilution water required was determined primarily by the strontium-yttrium fraction shipped. Another fact illustrated by the data shown for the period 1947 through 1949 is that, except for November 1949, the volume of dilution water required was less than one million metric tons* per month, whereas in 1950 the volume increased to

* To convert million metric tons to billion gallons multiply by 0.2642.
To convert million metric tons to billion cubic feet multiply by 0.03531.

as much as 4 to 6 million metric tons. The amount of dilution water required to reduce the I^{131} to the MPC appeared relatively constant during 1950. From Figure 3 it is obvious that most of the dilution water would be required by the strontium shipped. Iodine would require the next largest amount, and negligible amounts of dilution water would be required by the remaining radioisotopes listed in Table IV.

Decay Considered

To obtain more reliable information on the potential hazard, the procedure outlined above was repeated taking cognizance of the decay factor. In these computations an additional assumption was made, namely: that all radioisotopes were shipped at mid-month. Two estimates were considered: 1) an estimate of the hazard in each month based on shipments during the month, and 2) a cumulative estimate of the hazard based on a carry-over of radioactivity shipped during the previous months in accordance with the half-life of the radioisotope. In the first estimate the amount of each radioisotope shipped during the month was reduced by a factor corresponding to one-half months' decay and this value was divided by the MPC for the given radioisotope. The values obtained were plotted in Figure 4. In Figure 5, the

Insert Figures 4 and 5

cumulative millicuries shipped (reduced because of decay) were divided by the MPC values and plotted to show the volume of water required to reduce to tolerance the radioisotopes shipped from July 1947 to the given month.

For example, the value plotted for January 1950 includes the additive fractions of each radioisotope shipped during January and all months prior thereto. On this basis, to the amount of I^{131} shipped in January 1950 (reduced because of 15 days decay to 27.3 per cent of the I^{131} shipped) would be added 2.03 per cent of the I^{131} shipped in December 1949 and 0.15 per cent of the amount of I^{131} shipped in November 1949. In a similar manner, cumulative amounts were obtained for the other radioisotopes. Figure 4 shows that strontium required the largest volume of dilution water, and that increasingly greater amounts of dilution water are indicated for the strontium in Figure 5 because of the long half-life of Sr^{90} (25 years).

During the short period of shipment considered (July 1947 through December 1950), the amount of strontium lost by decay would be very small - a maximum of 9.2 per cent for the strontium shipped in July 1947. Therefore, without too much error under present conditions, it may be said that the volume of dilution water required for the total amount of strontium shipped (ignoring the effect of decay) may be used as an estimate of the dilution required for all radioisotopes. By this means the dilution water required amounted to 20.2 million metric tons as compared with 20.1 million metric tons (from Figure 5) for all radioisotopes listed in Table 4. The value of 20.1 million metric tons - about 5.1 billion gallons - is approximately equal to the volume of water used in 5 days by the City of New York and would be sufficient to dilute to MPC all of the activity in the radioisotopes shipped from ORNL.

From Figure 4, it will be seen that the maximum volume of dilution water required during any month to reduce the activity to the MPC was 5.54 million metric tons or 1.46 billion gallons which is a little more than the quantity of water used by the City of New York in one day. In other words, the maximum average amount of activity shipped during any month from ORNL could be diluted with the volume of water used in New York City during one day and be rendered innocuous when the calculations include the decay factor.

As mentioned earlier strontium is responsible for most of the dilution water required. This point may be illustrated somewhat differently as shown by the values reported in Table V. I^{131} and P^{32} which accounted

Insert Table V

for approximately 66 and 24 per cent of the cumulative millicuries shipped, respectively, were responsible for only 1.2 and 0.0 per cent of the potential cumulative hazard shown for December 1950 (Figure 5) whereas the $Sr^{89} + Sr^{90}$ and Y^{90} , which represents only 2.2 per cent of the millicuries shipped, was responsible for approximately 98.8 per cent of the estimated hazard in terms of the dilution required to reduce the activity to the tolerance values reported in Table IV. On the basis of the data given for October 1950 in Figure 4, I^{131} and P^{32} , which accounted for 61.7 and 16.1 per cent of the millicuries shipped, respectively, accounted for 4.4 and 0.3 per cent, respectively, of the total estimated hazard, whereas $Sr^{89} + Sr^{90}$ and Y^{90} , which represented 9.7 per cent of millicuries shipped, accounted for 95.3 per cent of the estimated hazard.

CONCLUSIONS

The computations described above are an attempt to estimate the degree of hazard in terms of the amount of dilution water required to reduce to tolerance specific radioisotopes shipped by the Operations Division (ORNL) during the period July 1947 through December 1950, and do not indicate the hazard at any particular locality in which radioisotopes are used. However, the method described, or refinements of the method, may be utilized to estimate the hazard at any particular locality, if the kinds and amounts of radioisotopes discharged are known.

Until more precise and more complete MPC data become available, it will be difficult to evaluate the degree of hazard which results from the discharge of off-Commission radioisotopes to the environment. However, this lack of knowledge does not relieve us of the responsibility of devoting our efforts to the problem of the discharge of radioactive wastes to sewers, streams and the atmosphere. A knowledge of the factors involved, of the amount and type of radioisotopes discharged and the evaluation of the potential hazard are of value in determining which radioisotopes should receive priority in the promulgation of rules and procedures for safe handling and disposal.

On the basis of the data presented, it is felt that standards and procedures, developed in the same manner as those in use for I^{131} , P^{32} , and C^{14} , should be indicated now, or as soon as circumstances permit, for the safe handling and disposal of strontium and perhaps other long-lived radioisotopes.

ACKNOWLEDGEMENTS

The writer wishes to express his appreciation to the Operations Division, ORNL, for the data on shipment of radioisotopes and to Dr. K.Z. Morgan for use of the data shown in Tables III and IV.

The work described in this report was performed at the Oak Ridge National Laboratory for the Atomic Energy Commission under Contract No. W-7405-Eng-26.

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Table I
Shipments of ^{131}I , ^{32}P and ^{14}C Compared to Total Shipments

Radioisotope	Aug. '46 - June '47 Shipments mc	Aug. '46 - Dec. '48 Shipments mc	Jan. '49 - Dec. '49 Shipments mc	Jan. '50 - May '50 Shipments mc	Aug. '46 - Dec. '50 Shipments mc
^{131}I	273	1,527	1,562	110,132.1	5,452
^{32}P	215	1,492	1,414	30,803.0	4,182
^{14}C	89	129.35	190	697.05	577
Total	577	3,304	3,166	141,632.15	10,211
Grand Total	959	4,534	4,334	190,888.59	15,156
% of Grand Total	60.2	73.0	73.1	74.4	67.5
Co^{60} (metal)			10	41,157.9	118
% of Grand Total			0.6	21.6	0.8
Omitting Co^{60} (metal) and re-computing percentages of ^{131}I , ^{32}P and ^{14}C					67.9
					89.5

* mc = millicuries

XXXXXXXXXXXXXXXXXXXX
See the following pages
for greater detail.
XXXXXXXXXXXXXXXXXXXX

Table I

Shipments of I^{131} , P^{32} and C^{14} Compared to Total Shipments

Radioisotope	Aug. '46 - June '47		Aug. '46 - Dec. '48		Jan. '49 - Dec. '49		Jan. '50 - Dec. '50
	Shipments	mc *	Shipments	mc	Shipments	mc	
I^{131}	273	10,296.3	1,527	69,783.9	1,562	158,845.55	
P^{32}	215	10,403.7	1,492	54,340.2	1,414	61,457.47	
C^{14}	89	129.35	285	860.4	190	1,386.64	
Total	577	20,829.35	3,304	124,984.5	3,166	221,689.66	1
Grand Total	959	22,482.75	4,534	129,186.97	4,334	275,221.61	2
% of Grand Total	60.2	92.7	73.0	96.7	73.1	80.4	
Co^{60} (metal)					10	44,880	
% of Grand Total					0.6	16.3	
Omitting Co^{60} (metal) and re-computing percentages of I^{131} , P^{32} and C^{14}							

* mc = millicuries

Table I

Shipments of I¹³¹, P³² and C¹⁴ Compared to Total Shipments

Aug. '46 - Dec. '48		Jan. '49 - Dec. '49		Jan. '50 - May '50		Aug. '46 - Dec. '50	
Shipments	mc	Shipments	mc	Shipments	mc	Shipments	mc
1,527	69,783.9	1,562	158,845.55	942	110,132.1	5,452	507,170.65
1,492	54,340.2	1,414	61,457.47	756	30,803.0	4,182	189,429.17
285	860.4	190	1,386.64	97	697.05	577	4,378.17
3,304	124,984.5	3,166	221,689.66	1,795	141,632.15	10,211	700,977.99
4,534	129,186.97	4,334	275,221.61	2,565	190,288.59	15,156	1,229,466.63
73.0	96.7	73.1	80.4	70.0	74.4	67.5	57
		10	44,880	25	41,167.9	118	445,414.5
		0.6	16.3	1.0	21.6	0.8	36.3
						67.9	89.5

Percentages of I¹³¹, P³² and C¹⁴

TABLE II.

Group

Activity Scale

1 μ c 10 μ c 100 μ c 1 mc 10 mc 100 mc 1 c

I. Slight Hazard
 $\bullet$ Na²⁴, K⁴², Cu⁶⁴, $\bullet$ Mn⁵², $\bullet$ As⁷⁶,
 As⁷⁷, Kr⁸¹, $\bullet$ Hg¹⁹⁷

II. Moderately Dangerous
 H³, C¹⁴, I¹³², $\bullet$ Na²², S³⁵, Cl³⁶,
 $\bullet$ Mg²⁸, Fe⁵⁹, $\bullet$ Co⁶⁰, Sr⁸⁹, $\bullet$ Nb⁹⁵,
 $\bullet$ Pu²³⁸, Pu²³⁹, Tl²⁰¹, Tl²⁰³, Tl²⁰⁵, I¹³¹,
 $\bullet$ Cs¹³⁷, $\bullet$ Ba¹⁴⁰, $\bullet$ La¹⁴⁰, Ce¹⁴⁴,
 Pr¹⁴³, $\bullet$ Nd¹⁴⁷, $\bullet$ Al²⁸, $\bullet$ Ag¹⁰⁸,
 H²⁰³, $\bullet$ Pb²¹⁰

III. Very Dangerous
 Ca⁴⁵, Fe⁵⁵, Sr⁹⁰, Y⁹⁰, $\bullet$ Fr²¹⁰,
 Ce¹⁴⁴, $\bullet$ Am²⁴¹, $\bullet$ Bi²¹²

Activity to be Handled in the Laboratory

Notes to Table 21

Effective radiotoxicity is obtained from a weighting of the following factors:

Half-life.

Energy and character of radiations.

Degree of selective localization in the body.

Rates of elimination.

Quantities involved and modes of handling in typical experiments.

The slant boundaries between levels indicate border-line zones, and emphasize that there is no sharp transition between the levels and the associated protection techniques.

The principal gamma emitters are indicated by asterisk (e.g. *Na²⁴).

The above system does not apply to the hazards of external irradiation.

The principal alpha emitters are not included because they are not commonly used except by AEC Operations.

Table III

Tentative Maximum Permissible Concentration for Certain Radioisotopes in
Water and Air* (3)

Element	$\mu\text{c/cc Water}$	$\mu\text{c/cc Air}$
U Nat. (sol.)	6×10^{-4}	1.7×10^{-11}
U Nat. (insol.)	-----	1.7×10^{-11}
U ²³³ (sol.)	1.5×10^{-4}	1×10^{-10}
U ²³³ (insol.)	-----	1.6×10^{-11}
Ra ²²⁶	4×10^{-8}	8×10^{-12}
Rn ²²²	2×10^{-6}	10^{-8}
Pu ²³⁹ (sol.)	1.5×10^{-6}	2×10^{-12}
Pu ²³⁹ (insol.)	-----	2×10^{-12}
Po ²¹⁰ (sol.)	3×10^{-5}	2×10^{-10}
Po ²¹⁰ (insol.)	-----	7×10^{-11}
C ¹⁴ (CO ₂)	3×10^{-3}	10^{-6}
H ³	0.2	2×10^{-5}
Ca ⁴⁵	5×10^{-4}	4×10^{-8}
P ³²	2×10^{-4}	1×10^{-7}
K ⁴²	1×10^{-2}	2×10^{-6}
S ³⁵	5×10^{-3}	10^{-6}
Na ²⁴	8×10^{-3}	2×10^{-6}
Cl ³⁶	2×10^{-3}	4×10^{-7}
Fe ⁵⁵	4×10^{-3}	6×10^{-7}

Table III (Continued)

Element	$\mu\text{c/cc Water}$	$\mu\text{c/cc Air}$
Fe^{59}	1×10^{-4}	1.5×10^{-8}
Mn^{56}	0.2	3×10^{-6}
Cu^{64}	8×10^{-2}	6×10^{-6}
I^{131}	3×10^{-5}	3×10^{-9}
Sr^{89}	7×10^{-5}	2×10^{-8}
$\text{Sr}^{90} + \text{Y}^{90}$	8×10^{-7}	2×10^{-10}
A^{41}	5×10^{-4}	5×10^{-7}
Xe^{133}	4×10^{-3}	5×10^{-6}
Xe^{135}	1×10^{-3}	2×10^{-6}
Co^{60}	2×10^{-2}	1×10^{-6}
Au^{198}	3×10^{-3}	1×10^{-7}
Au^{199}	7×10^{-3}	2.5×10^{-7}
Cr^{51}	0.5	8×10^{-6}
Ni^{59}	7×10^{-3}	4×10^{-7}
Mo^{99}	14	2×10^{-3}

*Under consideration for release by the Subcommittee on Internal Dose of the National Committee on Radiation Protection in Chicago, Illinois on January 16, 1951, Karl Z. Morgan, Chairman.

Table IV

Maximum Permissible Concentration of Radioisotopes in Water for ContinuousExposure*

Radioisotope	Radioactive Half-Life**	Maximum Permissible Concentration $\mu\text{c/cc}$
C ¹⁴	5,720 y	3×10^{-3}
H ³	12.5 y	0.2
Ca ⁴⁵	152 d	5×10^{-4}
P ³²	14.3 d	2×10^{-4}
S ³⁵	87.1 d	5×10^{-3}
Cl ³⁶	4.4×10^5 y	2×10^{-3}
Fe ⁵⁵	2.91 y	4×10^{-3}
Fe ⁵⁹	46.3 d	1×10^{-4}
I ¹³¹	8.0 d	3×10^{-5}
*** Sr ⁸⁹ + Sr ⁹⁰ + Y ⁹⁰	25 y	8×10^{-7} ****
Co ⁶⁰ (solution)	5.2 y	2×10^{-2}

*Continuously at 24 hours per day.

**Reference (7).

*** Sr⁸⁹ has a half-life of 55 days. Included with Sr⁹⁰ + Y⁹⁰ for convenience.

**** Based on a period of exposure of 10^4 days in the case of Sr⁹⁰ and indefinite exposure in the case of the other radioisotopes listed.

Table V

Comparison Between Millicuries Shipped and Estimated Hazard

(July 1947 - December 1950)

Radioisotope	Per Cent of Total			
	Millicuries Shipped		Potential Hazard	
	July 1947	October 1950	July 1947 December 1950*	Maximum Month**
C ¹⁴	0.57	0.47	----	----
H ³	6.02	11.55	----	----
Ca ⁴⁵	0.09	0.03	----	----
P ³²	23.91	16.12	0.0	0.3
S ³⁵	0.78	0.37	----	----
Cl ³⁶	----	0.02	----	----
Fe ⁵⁹	0.03	0.00	----	----
I ¹³¹	66.31	61.68	1.2	4.4
Sr ⁸⁹ + Sr ⁹⁰ + Y ⁹⁰	2.16	9.72	98.8	95.3
Co ⁶⁰ (Solution)	0.15	0.02	----	----

* From Figure 5.

** From Figure 4 for October, 1950.

List of Figures

(in order)

- Figure 1. Number of shipments of radioisotopes, Operations Division, Oak Ridge National Laboratory, by months for the period August 1946 through December 1950.
- Figure 2. Number of curies of radioisotopes shipped monthly by the Operations Division, Oak Ridge National Laboratory for the period July 1947 through December 1950.
- Figure 3. Dilution required to reduce to tolerance the specific concentrations of radioisotopes shipped monthly during the period July 1947 through December 1950. The effect of decay is not considered. ORNL data.
- Figure 4. Dilution required to reduce to tolerance the specific concentrations of radioisotopes shipped monthly during the period July 1947 through December 1950. The effect of decay is considered. ORNL data.
- Figure 5. Dilution required to reduce to tolerance the total specific concentrations of radioisotopes shipped during the period July 1947 through December 1950. The dilutions indicated are based on the cumulative total amounts of radioisotopes shipped during the period indicated. The effect of decay has been considered.









